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ANALYSIS OF KNOWLEDGE-BASED EXPERT SYSTEMS AS TOOLS FOR CONSTRUCTION DESIGN

A Special Research Problem

Presented to

The Faculty of the School of Civil Engineering

By

Arthur N. Cole

In Partial Fulfillment

of the Requirements for the Degree of

Master of Science in Civil Engineering

Georgia Institute of Technology

March, 1991

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AS TOOLS FOR CONSTRUCTION DESIGN

Approved:

Faculty Advisor

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The Need

Because construction costs are continuously rising, Congress mandated that those within the respective branches of military service who are responsible for planning and executing construction programs develop policies and procedures that ensure that the individual projects are designed, bid, and constructed as rapidly as possible. This requires an approach that demands maximum efficiency from the design process. Reviews are necessary to ensure that designs meet all requirements, but the reviews themselves must be conducted in the least amount of time so as to preclude delays. Such tardiness could result in important recommendations being given less than appropriate attention by the responsible designer and subsequent, costly post-award contract modifications.

A thorough review of construction design documents is a critical element of the procurement of professional design services. The owner, for whom the services are performed, wants to ensure that design provides the functional utility that he envisioned. At the same time, the designer has an interest in eliminating technical deficiencies, errors, omissions, and other inconsistencies in order to reduce his potential liability. The construction contractor is interested in discovering any interface problems and resolving any conflicts there may be between the

construction documents and the existing site conditions.

Flawed design documents "...can be the result of too short a time for preparation and review, laziness in not searching out the proper language, inadequate recognition of the proper assignment of risks, or just ignorance as to what is right and what is wrong for the particular project. They can also be the result of a client, particularly a public agency, providing rigid general conditions and format requirements...", (Riggs, 1979). Fortunately, since this observation was made, many changes have been implemented in the Federal Governments' procurement policy, which have culminated in the implementation of the Federal Acquisition Regulations (FAR). This document has codified and standardized the procurement policies and practices for all Federal agencies into a more enlightened approach similar to that being practiced in the private sector.

However, the FAR is not a panacea for problems with design deficiencies. These can derive from the methods specified within the FAR to procure the design services, which hastens the need for a thorough design review. In most cases involving military construction projects, professional construction management services are separate from the contract for design services. The designers obligation is complete and his services are terminated when he delivers a

final design that is deemed ready to advertise. From that point on, the process shifts focus to the award of the contract and the physical act of construction. The designer has little formal opportunity to interface with the contractor, except in conjunction with conflict resolution procedures. This fosters defensive attitudes among the parties and reinforces the need for error-free designs.

A study of the causes and costs of modifications to military construction contracts, by Mogren found that the major causes of modifications were design deficiencies, customer requested changes, and unknown site conditions. Of the design deficiencies, most were found to relate to Architectural aspects of the design, followed in frequency by errors in the Mechanical, then Electrical disciplines. The study found design deficiencies to account for 33.2% of the total number of change orders, and 36.3% of the total cost of all modifications. In both categories, design deficiencies were the greatest single statistic, (Mogren, 1986).

Regardless of the causes for design defects, the blame for them cannot be targeted solely at the designer. The level of influence over costs is greatest during the design phase, so it is then that knowledge brought to the design by the construction management expert will be most beneficial

(Stukhart, 1987).

In the public sector, construction management services are performed by the respective uniformed service component Engineer Corps, i.e., NAVFAC for the Navy, Corps of Engineers for the Army, etc. In the private sector, this function is performed under a Construction Management contract. In both sectors, the owner is given ample participation in the design process through the review of the design documents, usually at the 35% and 100% stages.

Construction managers contribute to the control of time, cost safety, and quality in the construction of a facility. In the opinion of the Construction Management Committee of the Construction Division of ASCE (Stukhart, 1987), construction managers "possess experience and a high degree of competence in the following:

1. Planning, organizing, directing, and controlling construction.
2. The latest construction technology.
3. Materials management, including availability and cost.
4. Quality management.
5. labor availability, use and productivity.
6. Cost engineering, including estimating and scheduling.

7. Contracting strategy.

8. Value engineering.

9. Risk management."

Given these skills, the construction manager can contribute to the constructability of the design by making recommendations regarding "contract packaging, construction sequencing, construction cost, access to work, safety, work rule and jurisdictional effects, construction methods, materials and minimization of construction interferences, as well as design detail improvements".

THE REVIEW PROCESS

The review of construction project plans and specifications ensures that they are technically adequate, functionally adequate, i.e., the project will result in a complete and usable facility that matches the users expectations and operational needs , and that the design is constructable. This places emphasis on the viewing the project in terms of its entire life-cycle (Kirby, 1988).

Technical reviews focus on the clarity of the documents from the viewpoint of the contractor. Points considered in a technical review include visual accuracy and clarity; i. e., are the details sufficient and clear enough so that a

prospective contractor will know without doubt the precise intent being conveyed? Are the design documents overly complicated? Are there ambiguities between separate drawings? Between the plans and specifications? Are the specifications complete and concise? Will the design result in reasonable and responsive bids?

Constructability implicitly relates the design to the materials and methods that will be needed to construct it. Such issues as ease of construction, efficiencies of labor productivity and equipment utilization, site conditions and layout, and others, are the focus of a constructability review. Are there methods and materials that would make the design easier to build without sacrificing the basic concept?

Operability refers to the considerations made during the design cycle that relate to the ease with which the facility can be operated and maintained. Anticipated facility life must be taken into consideration in the cost of and types of materials selected, as must anticipated future facility requirements. In addition, the design must be in compliance with current master plans and relate well architecturally to other facilities planned or existing nearby.

Basic NAVFAC policy governing the preparation and review of

design documents requires that technical, functional and constructability reviews be conducted at the 35% and 100% phases of design preparation. Prior to any external scrutiny, however, the persons preparing the specification are required to review the drawings to ensure that materials and systems appearing on them are covered and that all requirements necessary to accomplish the work are adequately expressed. Those preparing drawings are similarly required to review the specifications so as to ensure complete coordination (MIL-HDBK 1006/1, 1987).

Once the drawings and specifications have been coordinated, these technical, functional and constructability reviews are typically performed separately by groups of individuals in whom lies the special expertise required for each of the types of review. This includes the end-user, who may or may not have any expertise to properly review construction drawings and specifications. The reviews result in many comments from many people, each of whom has his own background, experience and bias. Coordination of all of these comments is the responsibility of the design project manager at the Engineering Field Division (EFD). He is the primary interface between the governmental agency proposing the project and the design Architect/Engineer firm contracted to perform the service. Typically, the EFD and the Installation requesting the work are geographically

separate which adds time for mailing and returning the plans, specifications, and comments. Depending on the size and complexity of the project, there could be hundreds of comments submitted by several reviewers at each stage of review. The design project manager is quite likely to be assigned several design projects to coordinate at any time.

All of this points to the difficulties that are routinely encountered and adds credence to the need for a viable review system that is time sensitive and considerate of the separate and diverse backgrounds of the many people conducting the review.

CHAPTER TWO

ABOUT EXPERT SYSTEMS

" An expert is a person who, because of training and experience, is able to do things the rest of us cannot; experts are not only proficient but also smooth nd efficient in the actions they take. Experts know a great many things and have tricks and caveats for applying what they know to problems and tasks; they are also good at plowing through irrelevant information in order to get at basic issues, and they are good at recognizing problems they face as instances of types with which they are familiar. Underlying the behavior of experts is the body of operative knowledge we have termed expertise. It is reasonable to suppose, therefore, that experts are the ones to ask when we wish to represent the expertise that makes their behavior possible". (Johnson, 1983)

Knowledge-based expert systems (KBES) are interactive computer programs that incorporate judgement, experience, rules of thumb, and other expertise, so as to provide knowledgeable advice about a specific domain. They mimic the thought process employed by a human expert in solving a problem. They are fundamentally different from the traditional, algorithmic types of computer applications that everyone is familiar with in several areas. Algorithmic programs process numbers. They are usually designed to solve a very narrow range of a specific family of problems. For example, algorithms are adept at determining the critical path in a complex construction schedule, or designing structural beams for certain specified combinations of loads. These programs can be quite sophisticated, but are sequential in nature and deal only with the information included in the procedural code of the program itself and any variable data that is input. Once the program begins its execution, it continues to completion, or until it is instructed to stop to pick up more data. It incorporates high-level knowledge, assumptions and rules of thumb, but these are built in to the programs code.

An algorithm cannot draw conclusions or make inferences. In essence these programs replicate the actions of a designer punching the numbers into his calculator. The program yields beam sizes or shear and bending moment data, just as the engineer would have arrived at himself. The major accomplishment of this type of program is that it frees the designer from the laborious

effort of performing the calculations himself. The family of algorithmic programs is to the calculator what the microwave oven is to the traditional kitchen device, namely a labor saver.

Knowledge-based expert systems are a major step forward in the development of the computer as a useful tool. KBES origins are fairly recent, coming out of research first conducted in the 1960's as an adjunct to the study of computer science called artificial intelligence (AI). Unlike their algorithmic number-crunching cousins, the early AI programs attempted to process symbols.

Early applications were cumbersome and extremely limited, just as the early algorithmic applications were. Beyond being able to solve certain puzzles, and perform other limited tasks, the more complicated the problem that was attempted, the longer the program took to solve it. These diminishing returns relegated the study of the usefulness of AI to institutions of higher education as not much more than an academic novelty.

Although the AI programs processed symbols, just as humans do, they were constructed using the experience gained in algorithmic processing. This meant that the information being processed was imbedded in the procedural code and manipulated in the same sequential, iterative process that is common to algorithms.

Practitioners soon realized that drastic improvements to the capability of the system could be achieved if the procedural, or control apparatus was separate from the knowledge being acted upon. This more closely resembles the way human inference works and is the most fundamental difference between KBES programs and traditional algorithms.

A KBES manipulates knowledge it possesses based upon recognitions that it is able to make because of the control strategy that is built into the system. "The central notion of intelligent problem-solving is that a system must construct its solution selectively and efficiently from a space of alternatives. When resource-limited, the expert needs to search this space selectively, with as little unfruitful activity as possible. An expert's knowledge helps spot useful data early, suggests promising ways to exploit them, and helps avoid low-payoff efforts by pruning blind alleys as early as possible. An expert system achieves high performance by using knowledge to make the best use of its time" (Hayes-Roth, 1983).

COMPONENTS OF A KBES

A discussion of the basic components of a KBES can be found in any of several books on the subject. The following discussion is taken from Waterman's A Guide to Expert Systems (Waterman, 1986),

and class notes from the course of instruction at the Georgia Institute of Technology CE 8113 "KBS for Civil Engineers".

THE KNOWLEDGE BASE:

The knowledge base in a KBES is organized using rules and facts. The rules may take the form of heuristics, or rules of thumb. These effectively define the limits within the domain to search. They are typically symbolic and not amenable to rigorous mathematical operation. Whereas an algorithm can act upon a small amount of knowledge with great speed and precision, guaranteeing an exact solution, the heuristic approach is to search selectively through a large knowledge base arriving at conclusions by comparing facts it has been given with knowledge that it already possesses, forming new knowledge in the process.

Knowledge is usually represented as rules or frames. Rule-based knowledge representation takes the form of the conditional I F - THEN-ELSE statement. As an example:

```
IF        This is a 35% design review
THEN      There should be a draft specification

IF        There is a draft specification
THEN      Check for wording "as directed"
               AND "where directed"
```

IF THEN rule examples:

IF	There is wording "as directed"
	OR "where directed"
THEN	Verify items are so indicated on drawings

IF	Facility is a truck fueling facility
THEN	Verify rigid (no hose) loading arms are indicated on drawings and in specifications

The current state is given in statements of fact. These are given separately, and represent the problem statement.

FACT	This is a 35% review
FACT	The facility is a truck fuelling facility
FACT	The project is located at NAS Atlanta

Facts are compared to the rules and matches are made, or not made. A match represents a new fact and it is compared to the set of alternatives until another match is made, and so on, until there are no more matches, or until the system is told to stop. The end-product is a conclusion that is based on inference chains made by comparing facts to rules.

Frame-based knowledge systems are specialized semantic networks. Each frame consists of information that is arrayed in a network of nodes and relations. The information within the nodes is arranged according to a hierarchy whereby the upper nodes are

more general, and the lower nodes are more detailed. Each node is defined by a collection of attributes such as name, size, configuration, etc., and values such as truck fueling facility, medium, multi-lane, etc. Each node inherits the properties of the those higher than it. The arcs connecting the nodes are called "isa". Because the properties of the individual nodes are known and the relations linking them, the "isa" are transitive, for any two nodes given, a third can be inferred. To illustrate, take the following example: "A Volvo is an automobile" and " all automobiles are motor vehicles". Thus, one can infer that a Volvo is a motor vehicle, even though it is not explicitly stated. The property inheritance hierarchy in the network is established by the "isa" arc.

THE INFERENCE ENGINE

The inference engine provides the means of using the domain knowledge to solve problems. That part of the inference engine that decides how to apply domain knowledge is the interpreter. That part of the inference engine that decides when and in what order to apply different pieces of domain knowledge is the scheduler. Together, these comprise the inference method used by the inference engine.

Some KBES use a "forward chaining" inference method. The production rules for such a method are written with a left hand side and a right hand side. These sides correspond to the

conditional IF ===> THEN statement. The chaining proceeds in the direction of the arrow. For example:

FACTS	RULES
A	IF F & B THEN Z
B	IF C & D THEN F
C	IF A THEN D

The first two rule each require facts that are not initially present so they cannot fire. However, because A is present, then D can be inferred, and added to the knowledge base. The rule A ===> D is removed since it has been satisfied. The next production rule to fire is C & D ===> F, since there is still not enough knowledge to satisfy the first rule. Now that the second rule has fired, F is inferred and added to the knowledge base, enabling the first rule to fire.

```
          Z
        /   \
      F       B
    /   \
  C       D
            \
              A
```

In this example, control begins at the bottom, and progresses forward to reach a conclusion at Z. The network assumes that all the related information below any particular node must be known before any forward movement can occur.

Taken in sequence, the inference process looks like this:

RUN	INITIAL FACTS		RULES	FINAL FACTS	
	A		F & B ===> Z	A	D
1	B		C & D ===> F	B	
	C		A ===> D *	C	
	A	D	F & B ===> Z	A	D
2	B		C & D ===> F *	B	F
	C			C	
	A	D	F & B ===> Z *	A	D
3	B	F		B	F
	C			C	Z

Forward chaining is data-directed and is not usually appropriate unless, as in the case above, there is only one situation (Z) that can be proven, given A,B, and C. A real-world network would

have hundreds or thousands of inference chains possible, some of which might be valid, but would not necessarily lead to the inference of the existence of Z. This strategy is inefficient in those cases.

On the other hand, a "backward chaining" inference method is goal-directed. Using the same information as in the example above, the object will be not to see what can be inferred from A, B, and C, but whether or not Z can be proven, given them. The system first checks to see if Z is already present in the set of known facts. Finding it absent, the system looks at the rules to see which of them produces the result, Z. Applying F & B ===> Z, to the facts, B is found, but F is absent. Now the system looks for the rule that infers F, and finds C & D ===> F. A search of the facts finds C, but not D. Finally, the system finds the rule A ==> D. Since it has found all matches that were previously absent, the system reverses itself by adding D to the knowledge base and executing the rules until it infers that Z exists.

```
        Z
      /   \
     F     B
   /   \
  C     D
         \
          A
```

The control begins at Z at the top of the network and progresses backward, trying to establish the existence of Z by proving the antecedents of Z. This network also assumes that all the information below any node must be known.

The backward chaining control strategy took the following steps to infer the existence of Z:

1. Z not present in facts.

   F and B needed to prove Z.
2. B present in facts, but not F.

   C and D needed to prove F.
3. C present in facts, but not D.

   A needed to prove D.
4. A present in facts.

   Infer the existence of D. Add to knowledge base.
5. C and D present in facts.

   Infer the existence of F. Add to knowledge base
6. F and B present in facts.

   Infer the existence of Z.

Control strategies can be further separated into "depth-first" or "breadth-first" chaining. Using the network below to illustrate, and assuming forward chaining, a breadth-first search would require that all of A, B, C, D and E be present in the facts before F, G, or H be considered. A depth-first search would require that A and B, only, be present in order to consider F. F and G must be present in order to consider I, and so on.

```
          K
         / \
       I     J
      / \     \
    F     G     H
   / \     \   / \
  A     B   C D    E
```

The backward chaining, depth-first operation would start at K, then move to either I or J (in no particular sequence). If I is true then F is tested, and so on. If F is false then G is tested. If both F and G are false, then J is tested. The breadth first procedure requires that both I and J must be considered before any movement to lower levels is considered. If I is not true, then H is considered, etc.

Different control strategies have different applications in the commercial market. Most shells written for PC use are depth first and can be either forward or backward chaining, but not usually both. Systems written for mini-computer or main frame use can be more flexible. YAPS, for instance, is forward chaining, but can be made to simulate backward chaining. Different programming languages, called expert system tools have been developed for different kinds of applications. EMYCIN was derived from MYCIN, an expert system developed to help diagnose and treat bacterial

infections. It uses IF-THEN rules to perform forward or backward chaining for rule-based knowledge applications. SRL uses frame hierarchies for inheritance and procedural attachment for frame-based knowledge applications. Common LISP (formerly Franz LISP) uses nested subroutines to organize and control program execution for procedure-oriented applications. There are also languages for object-oriented, logic-oriented, and access-oriented applications. A complete catalog of expert system tools can be found in (Waterman, 1986).

THE EXPLANATION FACILITY

The explanation facility is that part of the expert system that explains how solutions were reached and justifies the steps used to reach them.

THE KNOWLEDGE ACQUISITION FACILITY

Perhaps the most critical component to the system is not the knowledge-base itself, but how it is acquired. This is the function of the knowledge acquisition facility. The successful KBES must have both the appropriate knowledge and the means to use it effectively or there would be no need for it.

DOMAIN KNOWLEDGE

There is an immense amount of knowledge about technical and

functional aspects of a construction project, as well as about constructability issues. This knowledge is of two basic types; general or systemic knowledge-that which applies, more or less to all construction projects, and specific knowledge-that which is applicable to certain specific categories of construction. Put into context, a reviewer would generally check every design to ensure that items specified "as indicated" and "where indicated" were in fact shown to be so on the drawings. On the other hand, only an expert reviewer would have the specific knowledge to verify that rigid pipe (no hose) loading arms should be provided at POL facility truck stands, and that hoses were appropriate for rail off-loading only.

By using the Department of the Manual of Navy Facility Category Codes, P-72, knowledge bases can be developed that will include both general and specific knowledge for each specific type of facility listed. Specific knowledge about waterfront facilities may have little applicability to air control administrative buildings.

The notion of specialization is best demonstrated by the field of medicine where there are many separate groups of practitioners who know a great deal about a very narrow, yet complex field, but all have essentially the same prerequisite knowledge. Because there is an abundance of knowledge within the domain of medicine, and the knowledge can be organized by specialty, and meets a

number of other considerations that are discussed in the next chapter, there are more successfully functioning KBES than in any other professional endeavor.

FEASIBILITY DETERMINATION

A KBES may not be able to outperform an expert. It could be too slow, too expensive to develop or operate, too limited in its ability, or it may possess any number of other deficiencies. Therefor, it is well worth the effort to subject any task that is envisioned as a candidate for KBES development to a rigorous analysis that will demonstrate that the candidate task is suitable, justified, and appropriate.

SUITABILITY:

Waterman (Waterman, 1986) considers a task to be suitable for KBES development if the following conditions are met:

1. The task does not require common sense. Such a task would clearly be beneath the effort of a KBES.

AND

2. The task requires only cognitive skills. There is no requirement to physically manipulate anything, such as a bank of switches, or valves, etc.

AND

3. Experts can articulate their methods. The methods are not so complicated or so heuristic that they cannot be replicated.

AND

4. Genuine experts exist.

AND

5. Experts all agree on solutions.

AND

6. The task is not too difficult.

AND

7. The task is not poorly understood.

If all of these conditions can be satisfied, then the task is at least suitable for consideration for development. In this case, the task is performing technical, functional and constructability reviews of design drawings and specifications for construction contracts. The following comments are keyed to the points listed above to demonstrate the suitability of the task.

1. Design documents are an interdisciplinary undertaking between many design professionals. Each of their efforts must be coordinated with the other's. Not only must all of the lines on all of the drawings agree with each other, but the sizes that are shown and materials that are specified are the result of high level computations within

each discipline. In addition, design professionals are highly specialized within their respective disciplines. A competent Structural Engineer, for instance, may have very little knowledge of electrical power distribution design calculations, and would therefor not be able to detect obvious flaws in the types or sizes of equipment being specified and shown. It should be clear then that a person tasked with reviewing design documents who has little or no experience , i.e. a non-expert, would not be able to detect errors and omissions that are obvious to the practiced reviewer.

2. The task requires only cognitive skills. This is not as straight forward as it sounds. Often design documents specify certain equipment in generic terms in order not to be proprietary, and depict these as general shapes in the spaces they are intended to fit, when the actual equipment that will be installed will not be known until after the contract is awarded and the winning contractor submits his equipment catalog cuts for approval. Because there is usually a certain amount of variation among manufacturers, it takes a skilled reviewer to detect the possibility that the dimensions on the plan may not fit all of the possibilities of equipment configuration. While there is no physical manipulation per se, certain mental images must be constructed that approximate the same effect.

3. Most experts have their own "system" for reviewing plans and specifications, but they are almost all variations on the same theme. One of the better known of the published methods was developed and published by LCDR William Nigro, CEC, USN, entitled REDICHECK. This particular method is discussed in more detail later in the paper. There is other published information and a large number of resident experts to draw upon for this information.

4. In addition to the published literature on the subject, genuine experts exist within the NAVFAC family, mainly at the Engineering Field Divisions, but also at the Headquarters level, at the Navy Civil Engineering Laboratory, and at many of the Officer In Charge of Construction and Resident Officer In Charge of Construction (OICC/ROICC) field offices.

5. As alluded to in the paragraph on experts being able to articulate their methods, most use similar methods to begin with. Combining the best parts of all of them should not be difficult.

6. The procedure for reviewing plans and specifications for constructability is methodical and systematic and should be easy to emulate. The procedure is essentially the same for any review, with the variables being in the interaction

between the design disciplines themselves.

7. The need for and methodology of the thorough review of plans and specifications is well understood by all practitioners. The difference between them is their individual capabilities, which depends largely on the exposure each has had to the process, or EXPERTise!

JUSTIFICATION:

Once a task has been found to be suitable for development as a KBES, the next step is to determine if there is ample justification to proceed. One or more of the following considerations must be true in order for the task to be justifiable:

1. The task solution has a high payoff.

OR

2. Human expertise is being lost.

OR

3. Human expertise is scarce.

OR

4. Expertise is needed in many locations.

OR

5. Expertise is needed in a hostile environment.

One can easily see that conditions 1, 3, and 4 are met for

the task of developing a KBES to perform constructability reviews. It should come as no surprise to anyone involved in the construction industry that contract modifications arising from design deficiencies are expensive. The analysis by Mogren demonstrates this point. Those people who are currently employed that could be considered to be experts, are located mainly at the Engineering Field Divisions, and at the major OICC offices. Having genuine experts available at every field office on every occasion that a review is undertaken would be luxuriant, indeed.

APPROPRIATENESS:

The final review of a task to ensure that a KBES is appropriate is to make sure it has the following characteristics:

1. The nature of the task requires symbol manipulation, and heuristic solutions.

AND

2. The task is sufficiently complex to allow for the existence of genuine experts.

AND

3. The scope of the task indicates that it has practical value, and that it is of manageable size.

By carefully considering all of the aspects of the task of

reviewing construction project design drawings and specifications, it can be seen to be suitable, justified, and appropriate for development into a KBES.

CHAPTER THREE

THE STATE OF THE ART

CHECKLISTS:

Most of the domain knowledge that exists concerning reviews of this nature is in the form of checklists. At one end of the spectrum are lists that are general and quantitative in nature. These focus on macro issues and tend not to require any qualitative judgements. The review of a 35 % design submittal should ensure that the drawings contain certain minimum information, an outline project specification, a preliminary design cost estimate, initiation of certain back-up data such as economic analysis, or environmental assessments, and so forth. The reviewer can make sure that the specific items are physically there without having to make any serious value judgements about the actual design approach. This type of review is appropriate at the design project manager level (MIL-HDBK-1006/1, 1987).

At the other end of the spectrum are checklists that have evolved as the result of lessons that have been learned from experience. These typically take the form of helpful hints, tricks of the trade, and rules of thumb, collectively known as heuristics. The source of this body of knowledge comes

from designers, construction managers, constructors, users and maintenance specialists. One such checklist, REDICHECK (Nigro, 1983), was developed so that the ROICC could anticipate problems in time to solve them, project architects and designers could give design submittals a more thorough, interdisciplinary review, and A/E firms could benefit in reduced exposure to liability claims. It is a concise checklist, divided into seven major subdivisions, which contain sixty-two individual items to check or verify. It offers general advice that can be applied to the review of any facility design, such as to verify that items specified "as indicated" or "where indicated" are in fact indicated on the contract drawings as well as advice such as to verify that adequate ceiling height exists at worst case duct intersections. Both are examples of advice that one would expect an expert to be able to give to a novice.

The notion of providing expert advice is taken a step further in the USAF Engineering Technical Letter (ETL) 88-4, "Reliability and Maintainability (R&M) Design Checklist". In it there are seventeen major subdivisions with a total of over 600 specific individual items of advice. These appear to be derived mainly from the maintenance specialties and are no doubt the result of frequent occurrence. For example, in Section Three, Interior Electrical, item number 24 reads " Are explosion-proof fixtures/systems provided in areas

subject to flammable vapors? Areas of significant hazard are battery charging rooms, refueler vehicle maintenance bays, paint rooms and aircraft fuel system docks" (USAF ETL 88-4, 1988).

AUTOMATED CHECKLISTS:

Perhaps the most ambitious attempt to date to combine the best information available from all of the sources of knowledge, is embodied in the U.S. Army Construction Engineering Research Laboratory development (Kirby, 1988) of the Automated Review Management System (ARMS), and, more recently, the BCO Advisor. ARMS was developed beginning in 1985 as a result of the recognition that automated systems were already in place that had the capability of helping to coordinate the large numbers and complex diversity of comments in the relatively short times periods that are demanded. It is a UNIX based mini-computer program written in C that is accessible directly or through communications software/modem connections from any of the geographically separate parties having a hand in the review. The program is intended to be utilized primarily by the design project managers, review managers, reviewers and design A/E firms or in-house designers. It utilizes on-screen versions of the standardized hard-copy forms that have been used for comment generation, and other administrative documents relative to the review. The system is menu driven and user friendly. It

assists the design project manager by prompting him to initiate review routings on pre-planned dates. Returned comments are tracked in a report that informs the project manager on a continual basis the status of reviews including any which may be overdue. There are other features of the system to help the project manager plan future workloads as well.

The ability of the computer to sort through fields of data is an advantage that is exploited by ARMS. Comments can be sorted by location, discipline, topic, reviewer, designer, etc., into a useful file of information. Once comments have been received and organized by the project manager, they are forwarded to the design A/E for action. By stipulation, each comment must receive a response from the A/E. If he chooses to disagree with a comment, or has another reason not to incorporate it, then the matter is resolved at a meeting with the project manager and the reviewer. The ARMS system provides for a complete electronic record of all design review comments and their exact disposition. Because of the sorting ability of the computer, these comments and their resolution can be retrieved at a subsequent date in combinations or packages that can be used as "lessons learned" in the preparation of future designs, as well as for future reviews. In addition, it provides a concise record that can be helpful in the event of future A/E

liability claims and can also assist in providing the basis for evaluation of the A/E as well as the reviewers.

More importantly, the data base of knowledge grows incrementally with each comment/response pair. By using the sort feature, a complete file can be created that includes all attempted solutions to any problem. This will diminish those difficulties that seem to occur time and again.

The chief drawback to the system is the consistency of the comments. There are two major reasons for this; the personal expertise of the many different reviewers is widely divergent, and what expertise there is tends to be specialized within the design, maintenance, or operations disciplines, often leading to some aspects of a review receiving more attention than others. Another cause for the lack of consistency stems from the absence of a truly universal method for performing reviews. In addition, there is a considerable transiency among experts in the field. When they leave the organization, there is usually not another person with the same amount of expertise.

All of these reasons are classic demonstrations of the need for the development of a KBES. In response, USA CERL, developed the BCO (biddability, constructability, and operability) Advisor. It is an evolutionary step forward

from ARMS, designed to interface with it so as to draw on the existing capabilities, while providing additional input that will strengthen it even further by improving the generation of meaningful comments.

The program was developed using KBES technology, and is described by its developers as an expert system, although it should not be considered to be a full blown KBES in the sense that it will not arrive at an independent family of inferences, given a set of initial facts. Nevertheless, it is still a useful tool that interacts with the reviewer with easy to follow menus. The review results in a list of comments that are sent into an output file which also contains pertinent data such as the reviewer's name, project name, description, location, date of review, etc.

The program uses a multi-layered approach, with the reviewer being prompted with menus that steer him through the review process. At the uppermost level, the reviewer chooses between biddability, constructability, or operability reviews. Then he is given a choice between 35%, 95%, or Special Issues reviews.

The 35% review presents short lists of comments that are typical of those that a design project manager could expect to make to a design A/E firm. These lists are organized into

various categories of design discipline so as to permit the project manager to maintain a consistent train of thought during the review. In addition to the traditional design disciplines, there are also separate categories for environmental and operations and maintenance issues. The emphasis at the 35% level is on general concepts and design production issues rather than on qualitative issues.

The 95% review lists comments from the same set of design disciplines, but further divides the comments into subcategories corresponding to the CSI specification format, i.e., general conditions,sitework, concrete, etc. In all there are over 750 pre-written comments among the seven basic disciplines.

The special issues review option provides comments for specialized areas of interest such as life safety, security, construction scheduling, etc. There is also a category for "Special Facilities" which include such groups as waterfront operations, fueling, maintenance, and several others. Other categories, presumably, can be added as the need dictates.

By using the BCO Advisor, a reviewer without much experience, or with expertise in another discipline, is given a broad range of heuristics to use in the form of predetermined comments. The comments are presented to him in

a logical sequence, first by design discipline,then by CSI specialty within the discipline. Other considerations, based upon knowledge about environmental, operational and maintenance issues are also provided. Thus a relatively inexperienced reviewer is capable of performing a review with considerable scrutiny and the results are in a format that can be readily assimilated into the system so that those needing to be aware of his findings are made so with little time lost.

IMPROVING THE CONCEPT:

As written, the BCO Advisor lacks depth, even though the material to improve it is already embedded in the system. What the reviewer gets now is the same set of lists of comments regardless of the type of facility being considered. There are several hundred comments that may not apply to every type of facility. BCO Advisor recognizes that there are such things as "special facilities" that may need additional scrutiny, and includes them at a lower level, among several other categories in the special issues review option.

The concept that some facilities are somehow "special" should be expanded so as to recognize that all facilities are unique within certain specific categories. For the Department of the Navy, establishment of category codes,

nomenclature, facility type, and required units of measure for identifying, classifying and quantifying the various facilities is done by the NAVFAC P-72, Department of the Navy Facility Category Codes. There are nine broad DOD facility classes, which are subdivided into sixteen category groups. For example, the broad class of Operational and Training Facilities is further subdivided into three category groups, Operational (excluding waterfront), Waterfront, and Training. Within each of these category groups the individual specific facilities are assigned basic category numbers.

To illustrate, the following examples show how category codes are developed for a "Public Works Shop", and a "Water Distribution Line, Potable".

Facility Class	Category Group	Basic Category	Nomenclature
200			Maint & Prod Facil
800			Util & Grnds Improv
	210		Maintenance Group
	840		Water Util Group
		219	Facil Maint & Repair
		842	Water Distribution
		219-10	Public Works Shop
		842-10	Water Dist Line, Pot

A KBES to perform technical, functional, and constructability reviews should be able to access the knowledge base that it possesses in such a way as to infer which advice to give the reviewer based upon the type of review that is being performed as well as the type of facility that is being considered.

CHAPTER FOUR

THE NEXT GENERATION

COMBINING CADD, CCB, and ConDoc:

So far, the work that has been done in the burgeoning field of KBES development within the area of construction design review has been limited to the infusion of new software concepts with existing hardware in an attempt to solve the problem of correcting design deficiencies by improving the ability of reviewers to identify and provide high quality, consistent comments about them.

The next generation should embark on a plan to attack the problem of design deficiencies at the source, the drawing board. The use of Computer Aided Design and Drafting (CADD) systems is now prevalent throughout the design profession, and becoming more so as further development brings more system configurations to the market at more affordable prices.

CADD permits electronic coordination among design disciplines. Structural systems grids can be overlaid electronically with architectural plans to verify spacial continuity. Some of the CADD systems, such as the relatively

inexpensive AUTOCAD even permit study of all three dimensional planes so that spacial conflicts can be seen that would not appear in any two dimensional review.

Designers rightfully pride themselves on their ability to be innovative thinkers, yet the nature of drawing production has remained virtually unchanged, even with the widespread adoption of CADD systems. Computers have only replaced the drawing boards, not the methodology used to lay out the drawings. Contrast this with the enormously complex production of construction specifications. The Construction Specifications Institute (CSI) sixteen division specification format is the universally accepted standard within the Construction Industry. It simplifies and clarifies the enormous amounts of information that must be included in order to convey the intent of the design and the standards of expectation of the construction. Communications is thus vastly improved.

With the CSI approach in mind, Guzey and Freehof formulated the system called ConDoc in 1987 (Solomon, 1990). It standardizes the production of working drawings in the same way CSI did the specifications.

ConDoc begins by organizing the drawings first by major discipline, then within each discipline further subdivisions

occur that serve to keep similar drawings together. A standardized drawing identification system can thus be created. For instance, drawings related to the Architectural discipline are all labeled "A" followed by a number that specifies the nature of the drawing. The subdivisions of Architectural drawings are General Information (0), Plans (1), Exterior Elevations and Transverse Sections (2), Vertical Circulation (3), Reflected Ceiling Plans and Details (4), Exterior Envelope Details (5), and Interiors (6). A drawing labeled A203 is the third sheet of the exterior elevations and transverse sections group within the architectural discipline.

Additional standardization is applied to the sheet, itself, dividing it into zones for title block and legend information (zone 1), graphics (zone 2) and perimeter margin (zone 3). Within the graphics zone, which is understandably the largest portion of the sheet, is a grid composed of modules approximately 2" by 1 3/4". The module becomes the basic unit for sheet organization. Graphic details fit within one or more of the modules to form a module block. The module block can take up the entire graphics zone, or only part of it. Each module block has its own organization that parallels that used for the entire sheet, i.e. title block, graphics zone and perimeter margin.

The consistency which results lends itself well to CADD application. In addition ConDoc can link drawings with project specifications using keynotes that relate to the CSI specification format. The computer identifies the keywords appearing on a sheet and prints the specification sections that apply in the legend area of zone 1.

The power of this system can be even further enhanced by combining the ConDoc principle with the Construction Criteria Base (CCB). The CCB was created in the 1970's as a PC based program to aid in the production, modification, and distribution of Federal Guide Specifications. In its original form, it was contained on five 360 kilo-byte diskettes. Todays version of the CCB is Commercially marketed by the National Institute of Building Sciences (NIBS) on an annual subscription basis and is contained on four CD-ROM compact disks. The CCB has evolved into a system for electronic dissemination and use of design and construction criteria that includes guide specifications, design and technical manuals, building standards, and similar information. The system of electronic data bases contain private sector, military, and other federal agency guide specifications, technical manuals, standards, cost estimating programs, etc. Included are the complete library of vectorized drawings from NAVFAC P-272, "Definitive Designs for Naval Shore Facilities".

The CCB puts as much information of this kind at the fingertips of the members of the building community as quickly and cost-effectively as possible. Each CD-ROM disk effectively reduces the burdensome distribution of over 250,000 pages of printed information or 1,600 floppy diskettes of information that it contains.

The next generation involves a CADD system that is integrated with a KBES. The knowledge-base of the KBES has review oriented information discussed throughout this paper, and also design oriented information such as ConDoc and the CCB. A design project manager can coordinate the design and review with the integrated CADD system.

Design A/E firms are given much more definitive guidance and have the wherewithal to study the cost implications of changing materials or methods of construction. The designer will also have the best cumulative advice available from the construction managers, as well as operations and maintenance experts. Reviewers are given better design documents to examine during all phases of design production. There is adequate compensation for variations in individual expertise at every level.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

The problem that has been addressed by this paper is the existence of design deficiencies that remain undetected and cause expensive, post-award contract modifications. Because the owner is a willing participant in the design process, he is at least partially culpable if he does not properly review the design documents. Not every person who is assigned the task of reviewing design documents has the expertise to do so.

As indicated in chapter two, the task of performing technical, functional and constructability reviews is suitable, justifiable, and appropriate for development into a KBES using the concepts, hardware, and software that are available today.

Perhaps even more exciting is a vision of what follows next. With the adoption of ConDoc, and the existence of the Construction Criteria Base, existing CADD systems can be integrated with a knowledge-base that also includes heuristic knowledge provided by expert practitioners from the areas of construction management, operations, and

maintenance, into a powerful design tool that can dramatically increase the efficiency that will be even more important in the future.

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